True Confessions of the Biological Nutrient Removal Process

Sam Jeyanayagam

Nitrogen and phosphorus are essential growth elements for microorganisms used in wastewater treatment; therefore, during all biological treatment,some level of nutrient removal occurs. The resulting cell mass contains about 12 percent nitrogen and 2 percent phosphorus by weight. When a treatment system is engineered to remove nutrients greater than these metabolic amounts, it is called biological nutrient removal (BNR). In essence, BNR is comprised of two processes: biological nitrogen removal and enhanced biological phosphorus removal (EBPR).

Biological Nitrogen Removal

Key biological nitrogen removal reactions are nitrification and denitrification (**Figure 1**). Other related reactions include ammonification (conversion of organic nitrogen to ammonia nitrogen) and nitrogen uptake for cell growth.

Nitrification

Nitrification is the oxidation of ammonia to nitrite and nitrate. The key organisms involved are thought to be *Nitrosomonas* and *Nitrobacter*.These are autotrophs that oxidize inorganic nitrogen compounds for energy:

Nitrosomonas

$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$ + New cells

Nitrobacter

$2NO_2^- + O_2 \rightarrow 2NO_3^-$ + New cells

Carbon for cell growth is obtained from carbon dioxide. Consequently, organic substrate (BOD) is not a prerequisite for the growth of nitrifiers. Nitrite accumulation is typically not encountered in a fully nitrifying system because *Nitrosomonas* is slower growing; however, there is some indication that at wastewater temperatures of above 25 oC to 30 oC, nitrite-to-nitrate conversion may become rate-limiting, resulting in increased chlorine demand for disinfection.

It is now known that organisms other than *Nitrosomonas* and *Nitrobacter* can also mediate the nitrification process; therefore, the term ammonia oxidizing bacteria (AOB) is used to refer to them collectively.

In BNR systems, nitrification is the controlling process for two reasons:(1) AOBs lack functional diversity. They represent about 2 percent of the microbial mass. (2) AOBs have stringent growth requirements and are sensitive to environmental conditions.

Nitrification is strongly impacted by the following factors:

• ***Solids Retention Time (SRT)***: Since the growth rate of nitrifiers is slow compared to heterotrophs (BOD-removing organisms), longer SRTs are required for reliable nitrification. The nitrification SRT is a direct function of the wastewater temperature.

• ***Temperature***: The nitrification rate increases with temperature up to a certain point (30° C to 35° C), and then it decreases. A rule of thumb is that a temperature change from 20° C to 10° C will decrease the nitrification rate to approximately 30 percent, requiring about three times the mass of MLSS to produce an equivalent effluent ammonia concentration. Consequently, a system designed for winter nitrification can generally meet year-round ammonia nitrogen limits.

• ***Dissolved Oxygen (DO)***: The nitrification oxygen demand is approximately 4.6 mg of oxygen per mg of NH_4-N oxidized.When the DO drops to significantly below 2 mg/L for an extended period,nitrification would be inhibited.

• ***Alkalinity and pH***: Nitrification results in the destruction of 7.1 mg of alkalinity ($CaCO_3$) per mg of NH_4-N oxidized. If the influent contains inadequate alkalinity, nitrification would be compromised.As alkalinity is destroyed, pH is decreased and this could potentially reduce the nitrification rate. Most WWTPs operate in a pH range of 6.8 to 7.4.

• ***Inhibitory Compounds***: Nitrifiers are inhibited by certain heavy metals and organic compounds. Some polymers used in sludge conditioning are also inhibitory. Typically, inhibition is a concern if significant industrial discharges are present.

Nitrification results in the conversion of nitrogen from a reduced form (ammonia) to an oxidized form (nitrate). It is not in itself a significant nitrogen removal mechanism.

Denitrification

Denitrification must follow nitrification to achieve significant total nitrogen removal. Denitrification is the reduction of nitrate to nitrogen gas by certain heterotrophic bacteria. The process requirements are anoxic conditions and a source of rapidly biodegradable organic matter (RBOM). Anoxic refers to the presence of combined oxygen (nitrate and nitrite) and the absence of free or dissolved oxygen (DO). The simplified reaction is:

$NO_3^- + RBOM \rightarrow (N_2\,(gas) + CO_2 + H_2O + OH^-$ + New cells)

Denitrification results in the recovery of 3.6 mg of alkalinity as $CaCO_3$ and 2.9 mg of oxygen per mg of NO_3-N reduced; therefore, by combining nitrification (aerobic) and den-

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Figure 1: Biological Nitrogen Removal

Figure 2: Biological Phosphorus Removal

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itrification (anoxic), partial alkalinity recovery and oxygen credit can be attained. An additional benefit of incorporating an anoxic selector is improved sludge settleability.

The denitrification rate (g NO_3-N reduced/g MLVSS.d), which determines the amount of nitrate denitrified, is primarily a function of: (1) availability of RBOM, and (2) temperature.

• ***Availability of RBOM***: Denitrifiers, being heterotrophs, use organic matter as the energy and carbon source. As a first approximation, a minimum BOD:TKN ratio of about 3:1 is required in the bioreactor influent for reliable denitrification. The actual ratio will depend on operating conditions and substrate biodegradability. Within limits, higher F:M ratios in the anoxic zone achieve higher denitrification rates due to the presence of increased RBOM. Likewise, the type of substrate also impacts the denitrification rate. Significantly higher denitrification rates are possible with methanol and fermentation end-products, such as volatile fatty acids (VFAs) present in the influent wastewater. Denitrification supported by endogenous decay is associated with slow denitrification rates.

• ***Temperature***: Higher wastewater temperatures trigger increased microbial activity, leading to higher denitrification rates. For a given substrate (BOD) concentration, a temperature change from 20°C to 10°C will decrease the denitrification rate to approximately 75 percent.

Enhanced Biological Phosphorus Removal (EBPR)

As noted previously, the typical phosphorus content of MLSS in conventional secondary treatment is approximately 2 percent by weight. Enhanced biological phosphorus removal (EBPR) refers to phosphorus uptake greater than these metabolic requirements by specialized aerobic heterotrophs called Phosphorus Accumulating Organisms (PAOs).

Acinetobacter is the most widely recognized PAO. The phosphorus content of the biomass can be as high as 10 percent by weight, but is typically in the range of 3 to 5 percent; hence, the biological phosphorus removal capability of a system is directly related to the fraction of PAOs in the MLSS. Key process features that favor the selection of PAOs include:

• Anaerobic zone with adequate RBOM—in particular, volatile fatty acids (VFAs).
• Subsequent aerobic zone.
• Recycling of the phosphorus-rich return sludge to the anaerobic zone

In the anaerobic zone (**Figure 2**), the PAOs take up and store VFAs as carbon compounds such as poly-b-hydroxybutyrate (PHB). Note that PAOs, being aerobes, can not use the VFAs for cell growth in the anaerobic zone. Instead, the VFAs are used to replenish the cell's stored PHB for subsequent utilization in the aerobic zone. In other words, in the anaerobic zone the PAOs do not multiply, but get fat! The energy required for PHB accumulation is provided by the cleavage of another storage product, the inorganic polyphosphate granules. This splitting of energy-rich polyphosphate bonds results in the release of phosphorus and may be likened to a battery discharging.

In the subsequent aerobic zone, the PAOs use the internally stored PHB as a carbon and energy source and take up all the phosphate released in the anaerobic zone and additional phosphate present in the influent wastewater to renew the stored polyphosphate pool (recharging of the battery). This is because 24 to 36 times more energy is released by PHB oxidation in the aerobic zone than is used to store PHB in anaerobic zone; hence, the phosphorus uptake is significantly more than the phosphorus release. Net phosphorus removal is realized when sludge is wasted. When the phosphorus-rich return sludge is recycled to the anaerobic zone, the process is repeated (**Figure 3**).

In short, the complex biochemical reactions of the EBPR process are fueled by the cyclical formation and degradation of stored organic compounds (e.g. PHB), in concert with the degradation and formation of inorganic polyphosphate granules.

Some PAOs have the capability to denitrify. Denitrifying PAOs (DePAO) use nitrate instead of free oxygen to oxidize their internally stored PHB and effect phosphorus uptake in the anoxic zone.

The PAOs require higher energy than other heterotrophs (non-PAOs) to accomplish the cyclical reactions associated with the EBPR process. The two most critical factors that favor the proliferation of PAOs, and therefore the reliability of EBPR are: (1) the integrity of the anaerobic zone and (2) the availability of VFAs.

• ***Integrity of the Anaerobic Zone***: Strict anaerobic conditions must be maintained to provide the PAOs the first opportunity to take up the substrate. This means that the anaerobic zone should be protected from dissolved oxygen (DO) and nitrate sources, which eliminate anaerobic conditions and place the PAOs at a competitive disadvantage with other heterotrophs. Screw pumps and free fall over weirs

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Figure 3: Anaerobic-Aerobic Cycling for EBPR

Table 1: Potential Sources of VFAs at a Municipal WWTP

Table 2: BNR Process Reactions

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introduce DO into the influent. Likewise, the internal mixed-liquor recycle used in total nitrogen removal processes is a significant source of DO and nitrates, and the return sludge in nitrifying systems can also recycle nitrates. Unlike nitrification, the desirable SRT for EBPR is relatively low. When no nitrification is required, maintaining an SRT of about two to four days would prevent nitrate formation and its impact on the anaerobic zone.

• ***The Importance of Volatile Fatty Acids.*** The presence of adequate VFAs in the anaerobic zone is pivotal to achieving reliable EBPR. They have also been shown to enhance denitrification rates. All VFAs are not equally efficient in achieving EBPR. Acetic acid is thought to be the preferred VFA, while formic acid does not appear to be on the menu of PAOs. Recent studies have indicated that sustained and reliable EBPR is favored by a mixture of VFAs. Methanol, a rapidly biodegradable organic compound commonly used for enhancing denitrification, has not been implicated in EBPR. Volatile fatty acids can be generated by in-line sources within the main process stream or off-line sources (**Table 1**). The benefits and drawbacks associated with each of these options should be evaluated in detail before the preferred source of VFAs is selected.

Process Selection

The biochemical processes and microbial interactions associated with the BNR process are fairly complex. A working understanding of the various biological reactions, summarized in **Table 2**, is essential for designing, optimizing, controlling, and troubleshooting the BNR process.

The challenge facing designers and operators of BNR systems is to expose the microbial consortium to the required environmental conditions (i.e. anaerobic, anoxic, and aerobic) in the optimum sequence for the appropriate length of time. Considering the variations in influent flow and loadings (BOD and nutrients), this is easier said than done.

The selection of the most appropriate BNR process is generally based on influent characteristics and target effluent quality.

Influent Characteristics

The BNR process is very sensitive to influent characteristics. In particular, VFAs play a central role in enhancing phosphorus removal and denitrification rates. The BOD:TP and BOD:TKN ratios of the bioreactor influent are commonly used as indicators of wastewater's amenability to BNR. The minimum acceptable ratios are:

BOD:TP	20:1 to 25:1
BOD:TKN	2:1 to 3:1

If the influent BOD:TP is low (BOD limited), adequate VFAs may not be available and phosphorus removal could be compromised. Likewise, low BOD:TKN ratio could result in poor denitrification. Dilute influent, excessive BOD removal in the primary clarifiers, or significant recycled phosphorus and nitrogen loads from sludge processing operations may cause BOD limited conditions. A note of caution: The nitrogen and phosphorus loads in recycle streams from sludge handling and processing operations should be included in determining these ratios.

Target Effluent Quality

The target effluent quality used for process design should generally be lower than the permit requirements. As shown in **Figure 4**, the effluent TN and TP are comprised of the following components:

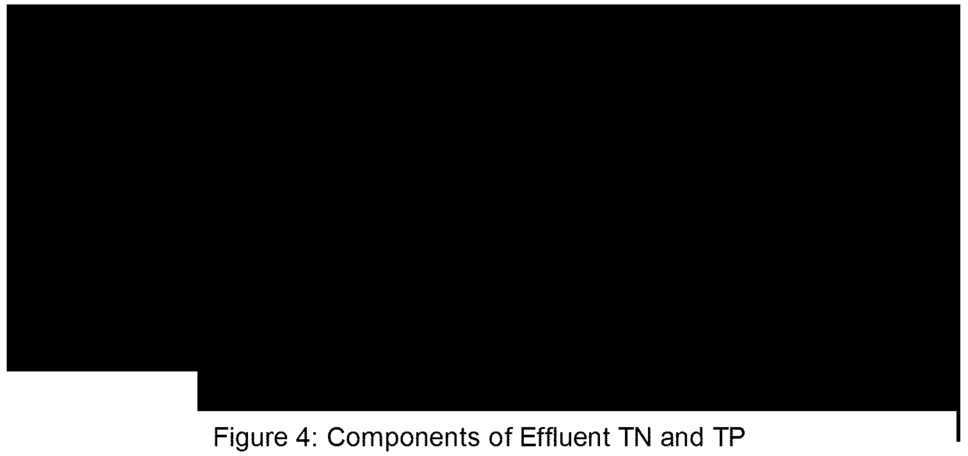

Figure 4: Components of Effluent TN and TP

Table 3: Effluent TN and TP Components and Achievable Limits

Effluent TN = (Ammonia-N) + (Nitrate-N) + (Particulate Organic-N) + (Soluble Organic-N)

Effluent TP = (Soluble-P) + (Particulate-P)

The various effluent TN and TP factions, the removal mechanisms involved, and the respective technology limits are shown in **Table 3**.

Soluble P removal can be accomplished by biological or chemical means. In biological phosphorus removal, the amount of VFAs available to the bugs will determine the effluent soluble P. In the case of chemical phosphorus removal, the chemical dose used will dictate the amount of soluble P precipitated; however, reaching very low effluent soluble P would require proportionally more chemical (surpassing the stoichiometric requirement), which would result in increased sludge production.

The lowest effluent TN limit that can consistently be achieved by technologies commonly used in municipal wastewater treatment is about 3 mg/L. Further reduction in TN may be achieved by targeting the larger nitrogen fractions, namely Nitrate-N and non-biodegradable soluble Organic-N. These can be removed by reverse osmosis (RO). However, doing so would prove cost-prohibitive and may not provide an overall sustainable environmental benefit, considering the need to dispose highly concentrated reject water from the RO system.

Particulate P removal is dependent on the solids capture effectiveness of the final clarifiers and effluent filters (if provided). In the absence of effluent filtration, an effluent TP of less than 0.7 mg/L can be achieved by enhanced biological phosphorus removal (EBPR) followed by good clarification.

Good solids control becomes increasingly important as the target effluent TP is lowered. The effluent solids from an EBPR system have an average phosphorus content of around 4 to 7 percent (dry weight basis) and can contribute significantly to the effluent total phosphorus levels. For example, as shown in **Figure 5**, 10 mg/L effluent TSS corresponds to about 0.4 mg/L effluent particulate phosphorus (assuming phosphorus content of 6 percent and VSS of 75 percent). Consequently, the higher the phosphorus content of the sludge, the lower the effluent soluble phosphorus will need to be for a given effluent TP.

Reaching less than 0.2 to 0.3 mg/L effluent TP would require granular filtration. Still lower TP levels (<0.05 mg/L) can be achieved with membrane filtration or ballasted flocculation, which increase solids capture capability. This means that the effluent TP permit limit may require the plant to achieve an effluent TSS that is lower than the permitted TSS value.

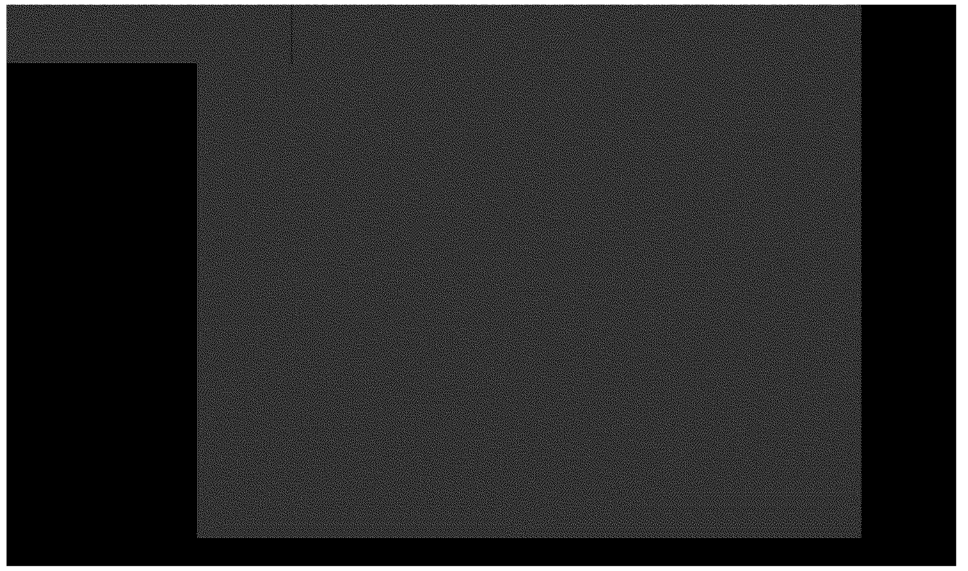

Figure 5: Impact of Effluent TSS on Effluent Particulate P

Process Configurations

The tank in which all the biological reactions take place is referred to as the bioreactor. Over the years, several bioreactor configurations have been developed to achieve TN and TP removal. All of them incorporate the anaerobic, anoxic, and aerobic zones. The differentiating features are the zone sequence and location of the recycle streams. Some of the common configurations are discussed below.

Nitrogen Removal Process Configurations

In the Modified Ludzack-Ettinger (MLE) process (**Figure 6**), the anoxic zone is placed ahead of the aerobic zone to provide the denitrification reaction the first opportunity to use the influent substrate. An internal mixed-liquor recycle (IMLR) is used to increase denitrification.

Typically, IMLR rates higher than 4Q (Q = Influent Flow) provide marginal benefits. Higher IMLR rates also increase the potential for DO recycle to the anoxic zone. Effluent TN level achievable with the MLE process is in the range of 6-8 mg/L.

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Figure 6: Modified Ludzack-Ettinger Process

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Figure 7: Four-Stage Bardenpho Process

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Figure 8: Step-Feed Configuration

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The four-stage Bardenpho configuration (**Figure 7**), includes a second anoxic zone for post-denitrification (endogenous or methanol-induced). This represents the Limit of Technology (LOT) for nitrogen allowing 3 mg/L TN to be reached consistently. The final aeration step is provided to drive out any remaining nitrogen gas so that it does not contribute to poor clarification in the final clarifiers.

Another LOT process configuration entails the use of denitrification filters following a nitrification system. Methanol addition would be required to sustain a viable nitrifier population in the filters. Both deep-bed and continuous backwash filters have been used for the purpose.

As illustrated in **Figure 8**, the step-feed system can be operated with an anoxic zone in each pass to produce 6-8 mg/L TN. Step-feed also offers other advantages, such as lower solids loading to the final clarifiers, higher SRT for the same tank volume, and prevention of solids washout during high-flow conditions by using the first pass for sludge reaeration.

Sequencing batch reactors (SBR) are capable of producing 6-8 mg/L TN with proper cycle times. The use of SBRs eliminates the need for final clarifiers; however, effluent equalization would be required to avoid sizing the downstream disinfection system for peak decant flow rates.

Combined Nitrogen and Phosphorus Removal Process Configurations

Biological phosphorus removal can be accomplished by placing an adequately sized anaerobic zone ahead of the aerobic zone to favor the growth of phosphorus-removing organisms. Facilities that have turned off the air supply in an effort to create an anaerobic selector at the beginning of the bioreactor have accomplished fairly good phosphorus removal.

Several potential configurations are available for combined nitrogen and phosphorus removal. These include A^2O (**Figure 9**), Modified University of Cape Town (**Figure 10**), Five-Stage Bardenpho (**Figure 11**), and the Johannesburg process configurations. Oxidation ditches have also been used to attain reliable BNR.

The typical configuration encompasses an anaerobic tank followed by the completely mixed oxidation ditch. Tight DO control allows simultaneous nitrification-denitrification to be achieved in the ditch. **Table 4** compares some of the commonly used BNR processes.

Other proprietary and non-proprietary processes that have been used for achieving various levels of nitrogen and phosphorus removal include Phased Isolation Ditch, Biolac, integrated fixed film activated sludge (IFAS) systems, biological aerated filters, trickling filters, and membrane bioreactors.

Design Considerations

Optimizing the complex BNR process entails maintaining a dynamic equilibrium among the functional groups and their interactions. System design should incorporate adequate flexibility to allow plant operators to respond to adverse operating conditions and influent variability. Here are some of the key design considerations for reliable BNR performance:

- Characterize the bioreactor influent using a minimum of two years of plant data. Unlike the secondary system, nutrient removal processes are extremely sensitive to influent characteristics and their variability. Recycle loads from sludge operations can modify the influent characteristics significantly and should be accounted for.
- Optimize nitrification first, since it is the controlling process and a prerequisite for denitrification. Next, optimize denitrification to achieve TN removal. Finally, maximize the biological phosphorus removal capability and consider chemical addition to accomplish additional phosphorus removal, if required.

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Figure 9: A^2O Process

Figure 10: Modified University of Cape Town Process

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• Temperature is the single most important factor in the design of nitrogen removal systems. Use the lowest monthly average temperature for nitrification design (see discussion on temperature impacts).

• Apply an adequate safety factor (1.5 to 2.5) to determine the design nitrification SRT. The safety factor provides a necessary margin of error and accounts for influent variability, MLSS fluctuations, and other unexpected operating conditions.

• Use a realistic denitrification rate to size anoxic volume to handle IMLR nitrate load. If the recycled DO in the IMLR is significant, the anoxic volume should be large enough to deplete this as well. For municipal WWTPs with primary clarification, the anoxic volume is typically 25 to 40 percent of the total bioreactor volume.

• Design structures to achieve even flow split to bioreactors and final clarifiers. Uneven flow distribution causes operational challenges and prevents the full treatment potential of the system from being realized.

• Ensure proper mixing of the bioreactor influent and return sludge, which have different densities. If they are not mixed well, BNR organisms will not be in contact with the substrate for the entire contact time, diminishing the nutrient removal efficiency of the system.

• Size the anaerobic zone to produce adequate VFAs for phosphorus removal and to remove nitrates in the RAS flow (if applicable). Substrate uptake and storage is normally a rapid reaction and not rate limiting.

• Anoxic and anaerobic mixers should be sized for proper mixing without entraining air. Submersible mixers are commonly used in modern BNR plants.

• Consider including primary clarifiers to remove "junk" solids. Primary clarification will increase the active biomass fraction of the MLSS and reduce the bioreactor volume.

• Use inter-zone baffles to preserve the integrity of the anoxic and anaerobic zones. Baffles should be designed to prevent backmixing by considering the density differential between aerated and unaerated zones, adequate forward velocities, and water-level drop between zones. Provide free passage for scum and foam.

• Provide selective surface wasting of scum and foam to avoid accumulation in the bioreactor.

• Consider providing intra-zone baffles to promote plug flow within a zone and achieve higher reaction rates by maintaining a concentration gradient.

• Control IMLR rate to minimize DO recycle. Consider a DO exhauster zone prior to IMLR withdrawal.

• Provide variable-speed IMLR and return sludge pumps.

• Provide flexibility to vary DO spatially within the aerobic zone to match demand. DO probes, on-line ammonia-nitrogen analyzers, ORP probes, or NADH measurements may be used to achieve tight DO control.

• Incorporate anoxic/aerobic swing cells if significant influent load fluctuations are anticipated.

• Avoid conditions that entrain air upstream of the bioreactor, such as screw pumps, free-fall weirs, turbulence, etc.

• Provide flexibility to waste sludge from the aeration zone. This practice will keep the sludge fresh and prevent secondary phosphorus release.

• Use state point analysis to examine final clarifier performance. Site-specific sludge settleability data should be used for this purpose.

• Avoid using a common suction header to withdraw sludge from multiple final clarifiers. Such a design prevents independent control of the sludge pumping rate from the various clarifiers.

• Incorporate strategies for managing recycle streams (see discussion below).

Operational Considerations

No matter how well designed a BNR system may be, proper operation is central to achieving its full nutrient removal potential. Some of the key operational considerations are discussed below.

Temperature

Biological reaction rates are temperature-dependent. The typical response is an increase in biological activity with temperature until a maximum rate is reached. Beyond this optimum temperature, biological reaction rates are inhibited as the temperature rises.

As a rule of thumb, a temperature change from 20° C to 10° C will decrease the nitrification rate to about 30 percent, requiring three times the mass of MLSS to produce an equivalent effluent ammonia concentration. Aerobic volume or MLSS should be increased in the colder months to compensate for reduced growth rates. Typically, nitrification inhibition sets in at around 40° C.

With respect to phosphorus removal, temperatures above 30° C appear to decrease the EBPR capability. This may be attributed to lower anaerobic VFA production rates and aerobic phosphorus uptake rates. Also at higher temperatures, PAOs are at a competitive disadvantage and are unable to compete effectively for the available VFAs in the anaerobic zone with organisms that do not accumulate PHBs, such as Glycogen Accumulating Organisms (GAOs).

DO Control

Avoid over-aeration. Controlling aera-

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Figure 11: Five Stage Bardenpho Process

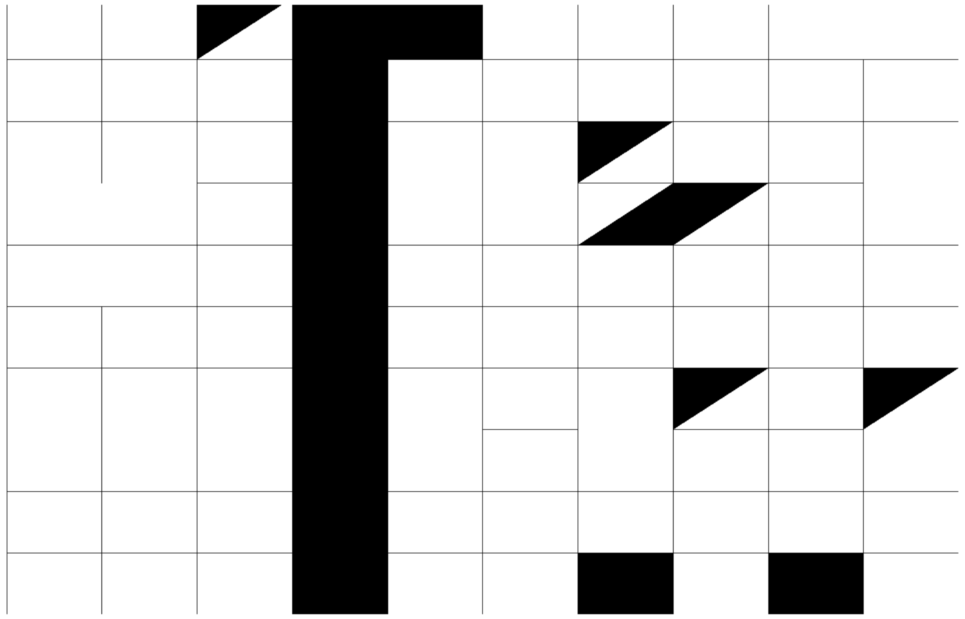

Table 4: Comparison of Common BNR Process Configurations

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tion zone DO is crucial to BNR performance. Air supply should be just sufficient to meet the carbonaceous and nitrogenous demands and achieve good mixing. Detrimental impacts of over-aeration include:
- Secondary phosphorus release due to cell lysis
- High DO in the IMLR flow
- High O&M cost

By maintaining low DO levels (0.5-1.0 mg/L) at the tail end of aeration zone, these problems may be avoided.

Tight DO control is also essential for promoting simultaneous nitrification/denitrification (SND), which occurs in the aerobic zone when regions low in DO are established within the floc. If sufficiently long SRTs are maintained, the low DO conditions can achieve significant denitrification without impacting nitrification. Complete mix systems (e.g. oxidation ditch process) rely on SND to achieve reliable TN removal without the use of baffled anoxic and aerobic zones.

Filamentous Growth

Conditions necessary for BNR are also favorable to filamentous growth,which could potentially cause poor settling in the final clarifiers. Filamentous growth may be controlled by:
- Creating anaerobic or anoxic selector zones to allow only floc-formers to access the food. By placing the filaments at a disadvantage, they are prevented from proliferating. It should be noted that selectors have not been found to be effective against organisms such as *Microthrix parvicella* and Type 0092.
- Chlorinating the RAS to kill filaments; however, overfeeding chlorine can be detrimental to the BNR process.
- Eliminating or controlling the operating conditions (low DO, low F:M, SRT, complete mix, etc.) that cause filamentous growth. Identifying the dominant filament would be helpful in determining the conditions that favor its growth. Consider using emerging and more accurate methods of filament identification, such as molecular fingerprinting. Using this technique, researchers at the University of Cincinnati were able to isolate *Paenibacillus* spp., a non-filamentous organism that traditional methods failed to identify. Their work indicated that this organism represented up to 30 percent of the biomass in the system investigated and contributed to the complete failure of the clarifier.
- Adding polymers to final clarifiers to enhance sludge settleability. Care should be exercised in selecting a polymer that neither inhibits nitrification nor contributes to effluent toxicity.

Scum and Foam

The most effective way to deal with scum and foam is to remove them from the biological system as quickly and completely as possible. Clarifiers should be designed with good scum removal facilities. Foam may be removed directly from the bioreactor by selective wasting from the surface. Accumulation in the bioreactor and re-inoculation of the influent stream should be avoided.Although the preferred method is to handle scum and foam separately,many facilities find it convenient to process them in the solids handling system.

Recycle Loads

Recycle streams from sludge processing operations could potentially impose significant additional nutrient loadings to the BNR bioreactor, surpassing the system's nutrient removal capability. The magnitude of the problem is dependent on the type of sludge processing and handling operations.The impact of recycle streams could be minimized by:
- Equalizing recycle flows
- Scheduling sludge processing/conditioning operations
- Treating the sidestreams

Secondary Release

Although VFA uptake is always associated with P release, P release could occur without concomitant uptake of VFAs. This is termed secondary release. Because there is no energy (VFA) storage, subsequent aerobic uptake of the released phosphorus may not be possible and elevated effluent phosphorus levels could result. Potential causes of secondary release include:
- Long anaerobic, anoxic, or aerobic retention times
- Co-settling EBPR sludge in the primary clarifier
- Septic conditions in final clarifiers due to deep sludge blanket
- Anaerobic digestion of primary and EBPR waste sludge
- Unaerated storage of the EBPR sludge
- Blending and storing primary and EBPR sludge

Conclusion

It is anticipated that an increasing number of WWTPs would be required to achieve nutrient removal in order to protect the aquatic ecosystem. The BNR process is a proven method of removing nutrients using naturally occurring microorganisms.

The primary objective of BNR plant operations is to achieve regulatory compliance consistently. Other objectives often include operational cost savings; process optimization; and a safe, clean workplace. Meeting these objectives demands proper design, operation, and management. Designers should incorporate features that would provide maximum process flexibility and ease of operation and maintenance. The plant staff, in turn, is responsible for operating the facility as intended and achieving the effluent goals.

The BNR process is mediated by several functional groups and is more complex than a secondary system. More than ever before, we are getting closer to understanding the competing and complimenting reactions at a microbial level. It behooves designers and operators of BNR systems to keep abreast of developments in the field, while contributing to the pool of knowledge by sharing their experiences and lessons learned.